SKETCH OF PROF. JOHN LE CONTE

SENSITIVE FLAMES AND SOUND-SHADOWS

BY

WALTER LE CONTE STEVENS

PROFESSOR OF PHYSICS IN THE PACKER COLLEGIATE INSTITUTE

TWO ARTICLES

REPRINTED FROM THE POPULAR SCIENCE MONTHLY

FOR NOVEMBER, 1889

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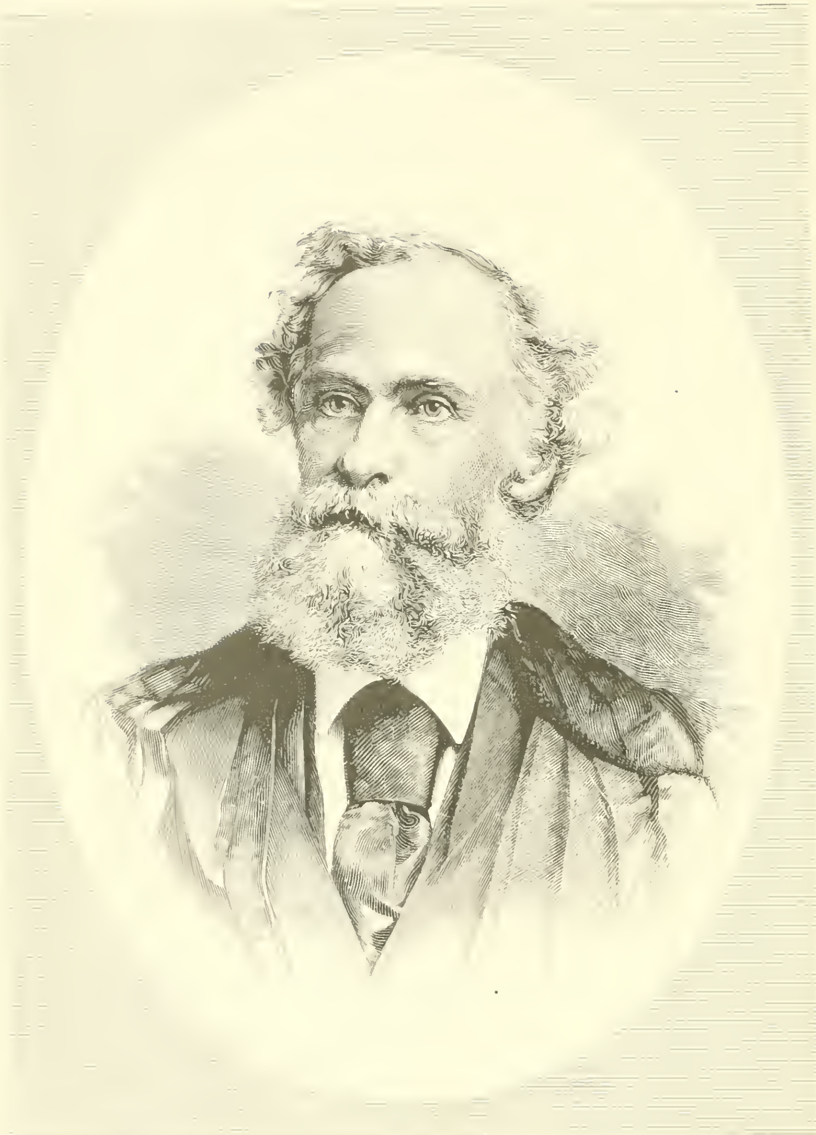

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THE subject of the present sketch is the Professor of Physics in the University of California, where he has for many years been associated with his brother, the distinguished geologist and writer on evolution. He was the second son of Louis Le Conte, and was born on the 4th of December, 1818, at the family homestead in Liberty County, Georgia. The father was a man of much independence of character, firm and decided, yet kind and gentle, exceedingly fond of investigation, original in thought, but singularly indifferent to popular recognition. He published nothing himself, and would never have become known away from his own home, had not others been appreciative enough of his real merit to give some of his results to the world by presenting them before the New York Lyceum of Natural History.

By personal influence and example, Louis Le Conte inculcated in his sons the love of science, and of truth for its own sake. The virtue of verification was one which he sought to cultivate in them as of cardinal importance. An illustration of the success of his teaching in this direction, and of the early growth of the philosophical habit of mind in his son John, was afforded on one occasion when the father and a number of neighbors, while patrolling at night to check some illicit transactions between the negro slaves and the shopkeepers of the nearest village, were fired upon with blank cartridges, and thrown from their startled horses. Relating the story of his mishap after he had reached home, the father said, "I lost my left stirrup; at the turn in the road I lost the other stirrup, and at the next turn I was thrown." John, who listened to the narrative with great interest, was perplexed to know how the stirrups could have been lost. His night's rest did not remove the trouble, and, leaving his bed before sunrise, he went and examined the saddle. He reported upon the result of his investigation at the breakfast-table. "Pa, did you not say last night that, when the horse ran away with you, you lost your stirrups?" "Yes, my son, I did say so." "Well, I have found that the stirrups are safe and sound." The laugh was turned against the son, and the father often told the story afterward as a joke upon him. It was, however, no joke; it was a prediction of the career of the future investigator in physics.

The childhood and most of the boyhood of John Le Conte were spent at the plantation home in Georgia, where hunting, fishing, boating, and all kinds of athletic sports contributed largely to the training of his observing faculties. His uncle, Major Le Conte,

an accomplished zoölogist, often gave up his New York home in winter for the purpose of spending the colder months on the Southern plantation. The scientific proclivities of both father and uncle insensibly made all the children students of natural history and collectors of specimens. Thus they gradually imbibed knowledge on such subjects, and acquired powers of discrimination that are ordinarily attained only by years of study in maturer life. Their mother died in 1826, leaving the father in charge of six children. Deprived of maternal care at so early a period of life, all of them, and especially the boys, were thrown largely upon their own resources at a tender age.

In those days and in that country neighborhood, forty miles from the nearest city, Savannah, it was necessary to do without the school accommodations that are now abundant in every village of our land. An isolated wooden-framed house, with no plastering, a single door for its single room, abundant ventilation through the crevices of the floor and walls, fully supplemented by the draught through an ample clay chimney—such was the school-house in which the children were gathered daily from plantations varying in distance from one to half a dozen miles or more. The teacher was rarely ever of the best. One there was who took charge of this road-side seminary for two years, became the intimate friend of Mr. Le Conte, and exerted over his boys an influence that became life-long. Alexander H. Stephens, the future statesman and historian, was then a young graduate who sought in teaching the pecuniary support that was necessary while he was preparing for admission to the bar. His fine classical taste and clear, logical mind produced a lasting impression upon John Le Conte, who received thus his training for college, and entered Franklin College, now the University at Athens, Ga., with distinguished success in January, 1835.

As a student, young Le Conte soon became noted for his clearness of conception and his scrupulous accuracy in work. The curriculum of study was the same for all, irrespective of native bias or prospective aim in life. He was fully appreciative of all the classical culture that was there afforded, but his tastes naturally led him into spending on mathematics and its applications a larger share of attention than Latin and Greek could attract. "Give him the cosine of A and he will prove anything," was the criticism expressed by an admiring fellow-student, and concurred in by the rest. The formal teaching of physics and chemistry involved mere text-book recitation, and attendance upon illustrated lectures of the most elementary character, which were delivered with oracular authority. It was more than whispered among the students that on these topics John Le Conte knew as much as or more than the professor himself.

During his senior year at college Mr. Le Conte was bereft of his devoted father, who died after a very brief illness. This calamity hastened his selection of a profession. In August, 1838, he was graduated with high honor. Immediately afterward he began the study of medicine, and in the spring of 1839 he entered the College of Physicians and Surgeons in New York, where, in March, 1841, he received the degree of Doctor of Medicine. A few months before his graduation in medicine another domestic calamity befell him in the death of his eldest brother, William, to whom had been committed the charge of the family estates in Georgia. This event hastened Dr. Le Conte's return home in the spring of 1841, to take charge of the estate as the eldest surviving son, and frustrated the execution of a cherished plan for supplementing his medical education by a year's residence in Paris.

During the summer of 1841 Dr. Le Conte returned to New York, and was married in July to Miss Josephine Graham, of that city, an accomplished young lady of Scottish and English extraction. The deep love and earnest devotion, and the consequent domestic happiness which crowned this union, contributed more than all else afterward to fortify and sustain him in the battle of life. Mrs. Le Conte was a woman of wonderful personal magnetism, queenly in bearing, and of extraordinary beauty. Her brilliancy and wit, her quick insight and ready tact, added to her majestic presence, made her the center of attraction in every social gathering. In after-years, especially at the annual meetings of the American Association for the Advancement of Science, such men as Bache, Peirce, Henry, and Agassiz vied with each other in doing her homage. Her fame in social circles equaled that of her husband among men of science; and no important step in his life has been taken without acknowledgment of the help derived from the social influence of a wife of whom he was justly proud.

In the autumn of 1842 Dr. Le Conte established himself as a practitioner of medicine in Savannah, Georgia. His four years of residence in that city formed no exception to the usual experience of a young doctor: a very small practice and an increasing family. It afforded, however, an excellent opportunity for study and research, and it was during this period that he made his most important contributions to medical literature. These at once established his reputation in the profession as an acute observer, cautious, exact, and industrious. The first of them, entitled "A Case of Carcinoma of the Stomach," published in the "New York Medical Gazette" in 1842, was the initial outcome of a series of observations on cancer that has been continued from time to time, even after Dr. Le Conte's abandonment of the practice of medicine. At this period he probably paid more attention to physiology than to any other of the departments included in medical science, and his

fondness for research interfered to some extent with the efforts that might have been made to secure paying patients.

In August, 1846, Dr. Le Conte accepted the chair of Natural Philosophy and Chemistry in Franklin College, his *alma mater,* from which he had gone forth eight years before as the best scientific student in his class. This decided his withdrawal from the field of practical work in medicine. Henceforth he devoted himself to the study of physical science, but without failing to keep pace still with the progress of physiology. He retained his professorship at Athens for nine years, resigning it in the autumn of 1855 to become lecturer on chemistry in the College of Physicians and Surgeons, his medical *alma mater.* In the spring of 1856, at the conclusion of his course of lectures in New York, he accepted a call to the South Carolina College at Columbia, where he had been unanimously elected to fill the chair, then first created, of Natural and Mechanical Philosophy. This position he held until the college was disbanded soon after the opening of the civil war. He was then put in charge of the Niter and Mining Bureau of South Carolina. In 1866 the University of South Carolina was organized, and Dr. Le Conte was elected to the same chair that he had held in the college of which this was the new development. This position he retained until 1869, when he gave up his residence in Columbia to become an adopted citizen of California. Here his home has continued up to the present time.

The period of thirteen years embracing Dr. Le Conte's connection with the South Carolina College and University, although clouded by the saddening events incident to the civil war, constituted the pleasantest and most satisfactory period of his life. The institution was governed by a board of trustees composed of gentlemen of refinement and culture, who entertained a genuine sympathy for the labors of the student who strives to plant himself at the most advanced outposts of science and literature. The community amid which the college had been developed was strongly influenced by the atmosphere of scholarship which it produced. There was a quiet spirit of encouragement to learning, which, by its freedom from pretension, furnished the most grateful incentive to study. It was during these years that Dr. Le Conte established a European reputation through his writings, which were published chiefly in the "American Journal of Science" and the "London Philosophical Magazine." It was in 1857 that he made the remarkable discovery of the sensitiveness of flame to musical vibrations—a discovery which served as the starting-point for Barrett, Tyndall, and Koenig in the exquisite applications that have since been worked out by the use of flame for the detection of sounds too delicate for the ear to perceive, and for the optical analysis of compound tones. Unfortunately,

Dr. Le Conte did not possess the wealth of instrumental appliances needed for the development of his unique discovery, but his priority was gracefully proclaimed by Tyndall in the now classic book on sound, made up of lectures delivered at the Royal Institution. Among other papers that attracted marked attention in Europe was one "On the Adequacy of Laplace's Explanation to account for the Discrepancy between the Computed and the Observed Velocity of Sound in Air and Gases," written in 1861 and published in 1864. Laplace's modification of Newton's formula had been questioned by eminent English mathematicians and physicists. Dr. Le Conte showed that the obscurity into which the subject had been thrown was due to misconception of the physical theory of Laplace, and to the difficulties and obscurities which invest the mathematical theory of partial differential equations in their application to physical questions. This paper evoked replies from Profs. Challis, Earnshaw, and Potter, in England; but the American physicist's position is generally accepted today. The paper is a model of exact physical reasoning. In addition to the discussion of Laplace's views, it contains an original investigation of the bearing of the phenomena attending the propagation of sound in air on the question whether the gases constituting our atmosphere are in a state of mixture or of combination.

Just before the close of the war the home of Dr. Le Conte was included in the belt of desolation that was left by General Sherman's march through South Carolina. Among the losses by fire was the manuscript of a volume on general physics, the product of Dr. Le Conte's many years of experience as a teacher and student of this subject. The tribulations of the reconstruction period in South Carolina during the years following the war made scientific investigation impossible. The political turmoil, and the inauguration of the rule of ignorance and vice in place of intelligence, left no refuge but expatriation for those whose occupations depended upon the embellishments of civilization. To this source of disquietude was added the burden of domestic affliction in the loss of an only daughter in the bloom of early womanhood.

At this critical time came a call to the Pacific coast, to assume the chair of Physics and Industrial Mechanics in the University of California, which was then in the incipiency of its organization. The offer was accepted, and Dr. Le Conte arrived in San Francisco in April, 1869. Being immediately appointed acting president, he drew up the first prospectus of the university, in which was set forth a synopsis of the proposed courses of instruction. In September of the same year exercises were begun in temporary buildings at Oakland, where during the following summer he conferred the baccalaureate degree on three young men,

and then retired from executive duties in order to build up more thoroughly his own department of work. On the resignation of President Gilman in 1875, Dr. Le Conte was induced again to assume the presidency, which he retained until June, 1881, but still performing the duties of his professorship. Since that date he has confined himself to his chair of Physics.

Through nearly the whole of life the two brothers, John and Joseph Le Conte, have been closely associated, each attaining eminence, the elder as a physicist, the younger as a geologist. The elder preceded the younger by six years at Franklin College, in Georgia. They went almost together to the South Carolina College, and likewise to the University of California. This fact has often led to their names becoming confounded by strangers.

Dr. Le Conte is a member of the National Academy of Sciences, the American Association for the Advancement of Science, the American Philosophical Society and Academy of Natural Sciences in Philadelphia, the New York Academy of Sciences, and the California Academy of Sciences. To this list might be added various other bodies which have bestowed upon him honorary membership.

A list of some of the more important of Dr. Le Conte's published writings is appended. The entire list is too long for insertion, amounting to about a hundred papers.

Of the first dozen, which show the direction of his tastes as a physician, perhaps the most interesting is No. 9, in which by original experiments he proved that the alligator is able to execute deliberate and determinate movements after decapitation and even after destruction of the spinal cord.

In No. 10 he shows that the mortality from cancer has increased in modern times; that it augments regularly with increasing age, and that it is greater in France than in England. The same subject is pursued still further in No. 28 and No. 49, in which he shows important errors in the usual methods of interpreting vital statistics, and that the average mortality from cancer is fully three times as great among females as among males.

In No. 16 he gives the first rational explanation of a whole class of ice phenomena as manifested both in the ground and in plants. In No. 17 the investigation is continued, and from numerous experiments it is shown that many plants may be completely frozen without injury.

No. 19 is a criticism of Moseley's theory of the descent of glaciers, in which it is demonstrated that the descent can not be produced by expansions and contractions of the ice due to changes of temperature.

In No. 20 it is shown that Maury's theory of the winds is un-

tenable. This conclusion is now universally accepted, great as was the value of Maury's work in the pioneer days of meteorology.

In No. 23 it is shown that solar light has no sensible influence on combustion. This paper, as well as Nos. 16 and 17, was extensively reproduced in Europe. The same remark applies to Nos. 24 and 26, which have been already discussed.

In Nos. 25 and 39 an account is given of investigations regarding the depth, transparency, and color-tints displayed in some remarkable bodies of water.

No. 35 contains the description and discussion of some unique experiments on the propagation of vibrations through water, the source of disturbance being explosions of great violence. The results were wholly new, and attracted much attention in Europe.

In Nos. 37 and 41 the principles of capillarity are very thoroughly discussed, and illustrated by some new experiments.

Many others of these papers might be summarized, but only by exceeding the limits of a brief biographical sketch.

SCIENTIFIC.

1. "Case of Carcinoma of the Stomach" ("New York Medical Gazette," 1842).

2. "On the Mechanism of Vomiting" ("New York Lancet," 1842).

3. "On Carcinoma in General, and Cancer of the Stomach" (ibid., 1842).

4. "On the Explanatioñ of the Difference in Size of the Male and Female Urinary Bladder" (ibid., 1842).

5. "An Essay on the Origin of Syphilis" ("New York Journal of Medical and Collateral Sciences," 1844).

6. "Remarks on Cases of Inflamed Knee-Joint" (ibid., 1844).

7. "Extraordinary Effects of a Stroke of Lightning.—Singular Phenomena" (ibid., 1844).

8. Observations on Geophagy" (Southern Medical and Surgical Journal," 1845).

9. "Experiments illustrating the Seat of Volition in the Alligator, or Crocodilus Lucius of Cuvier. With Strictures on the Reflex Theory" ("New York Journal of Medical and Collateral Sciences," 1845 and 1846).

10. "Statistical Researches on Cancer" ("Southern Medical and Surgical Journal," 1846).

11. "On the Quarantine Regulations at Savannah, Ga." ("New York Journal of Medical and Collateral Sciences," 1846).

12. "Remarks on the Physiology of the Voice" ("Southern Medical and Surgical Journal," 1846.

13. "Dr. Bennet Dowler's Contributions to the Natural History of the Alligator" (ibid., 1847).

14. "On Sulphuric Ether" (ibid., 1847).

15. "The Philosophy of Medicine: An Address" (ibid., 1849).

16. "Observations on a Remarkable Exudation of Ice from the Stems of Vegetables, and on a Singular Protrusion of Icy Columns from Certain Kinds of Earth during Frosty Weather" ("Proceedings of the American Association for the Advancement of Science," 1850; also, "Philosophical Magazine," 1850).

17. "Observations on the Freezing of Vegetables, and on the Causes which enable some Plants to endure the Action of Extreme Cold" ("American Journal of Science," 1852; also "Proceedings of the American Association for the Advancement of Science," 1851).

18. "On the Venomous Serpents of Georgia" ("Southern Medical and Surgical Journal," 1853).

19. "On the Descent of Glaciers" ("American Journal of Science," 1855).

20. "Review of Lieutenant M. F. Maury's Work on the 'Physical Geography of the Sea'" ("Southern Quarterly Review," 1856).

21. "The Mechanical Agencies of Heat" (ibid., 1856).

22. "Influence of the Study of the Physical Sciences on the Imaginative Faculties." An Inaugural Address, delivered December 1, 1857 (Columbia, S. C., 1858).

23. "Preliminary Researches on the Alleged Influence of Solar Light on the Process of Combustion" ("American Journal of Science," 1857; also, "Proceedings of the American Association for the Advancement of Science," 1857; and "Philosophical Magazine," 1858).

24. "On the Influence of Musical Sounds on the Flame of a Jet of Coal-Gas" ("American Journal of Science," 1858; "Philosophical Magazine," 1858).

25. "On the Optical Phenomena presented by the Silver Spring in Marion County, Florida (U. S.)," ("American Journal of Science," 1861; also, "Proceedings of the American Association for the Advancement of Science," 1860).

26. "On the Adequacy of Laplace's Explanation to account for the Discrepancy between the Computed and the Observed Velocity of Sound in Air and Gases" ("Philosophical Magazine," 1864).

27. "Limiting Velocity of Meteoric Stones reaching the Surface of the Earth" ("Nature," 1871).

28. "Vital Statistics: Illustrated by the Laws of Mortality from Cancer" ("Western Lancet," 1872).

29. "Heat generated by Meteoric Stones in traversing the Atmosphere" ("Nature," 1872).

30. "The Nebular Hypothesis" ("Popular Science Monthly," 1873).

31. Articles on "Bonanza," "Comstock Lode," and "Death Valley," in "Johnson's Cyclopædia," vol. iv, Appendix, 1876.

32. "Mars and his Moons" ("Popular Science Monthly," 1879).

33. "Origin and Distribution of Lakes; Meteorology of the Pacific Coast" ("Mining and Scientific Press" and Supplement, 1880–'81).

34. "Influence of Modern Methods of popularizing Science" ("Berkeleyan," 1882).

35. "Sound-Shadows in Water" ("American Journal of Science," 1882; also, "Philosophical Magazine," 1882).

36. "Origin of Jointed Structures in Undisturbed Clay and Marl Deposits" ("American Journal of Science," 1882).

37. "Apparent Attractions and Repulsions of Small Floating Bodies" ("American Journal of Science," 1882; also, "Philosophical Magazine," 1882).

38. "Amount of Carbon Dioxide in the Atmosphere" ("Philosophical Magazine," 1882).

39. "Physical Studies of Lake Tahoe" ("Overland Monthly," three papers, 1883–1884).

40. "The Part played by Accident in Discoveries" ("Berkeleyan," 1884).

41. "Horizontal Motions of Small Floating Bodies, in relation to the Validity

and Postulates of the Theory of Capillarity" ("American Journal of Science," 1884; also, "Journal de Physique," 1885).

42. "Criticism of Bassnett's Theory of the Sun" ("Overland Monthly," 1885).

43. "The Evidence of the Senses" ("North American Review," 1885).

44. "The Metric System" ("Overland Monthly," 1885).

45. "Thought Transference" (ibid., 1885).

46. "Barometer Exposure" ("Science," 1886).

47. "Electrical Phenomena on a Mountain" (ibid., 1887).

48. "Standing Tiptoe; a Mechanical Problem" (ibid., 1887).

49. "Vital Statistics, and the True Coefficient of Mortality, illustrated by Cancer" ("Tenth Biennial Report of the State Board of Health of California," 1888).

50. "The Decadence of Truthfulness" (1889).

About fifty additional papers are omitted from this list.

SENSITIVE FLAMES AND SOUND-SHADOWS.

By W. LE CONTE STEVENS,

PROFESSOR OF PHYSICS IN THE PACKER COLLEGIATE INSTITUTE.

THE conception that sound is due to wave-motion in an elastic material medium was first distinctly expressed in the sixteenth century by Lord Bacon. He distinguished between local motion in a medium and the propagation of this motion through it, referring to the transmission of sound through both air and water by way of illustration. For measuring the velocity of sound in air he proposed a plan which has been repeatedly applied since his time, that of firing a cannon and noting the interval between the flash and the report as heard at a measured distance.

It is impossible now to determine how far these observations may have been original with Bacon, or to what extent they may have expressed the current knowledge of his time. They were clearly apprehended by Galileo, who discovered the law of simple harmonic motion and made the first well-authenticated experiments on the relation between vibration frequency and musical pitch. But it is to Sir Isaac Newton that we must give the credit of first applying the wave theory rigorously to the phenomena of sound. Assuming this theory, he showed the possibility of calculating what ought to be the velocity of propagation through any medium of known elasticity. He deduced a formula which has been found applicable to most media. In the case of atmospheric air it failed, but because it required a correction dependent on certain laws of heat which had not then become known. The correction was made by Laplace, and the formula, as thus completed, is now found to be applicable to all known gases. This was only one of the many important principles established on a mathematical basis in the "Principia," and published in 1687.

Even before this date, the conception that light, as well as sound, might be due to wave-motion seems to have been grasped by a few thinkers. In 1665 a book on "Light and Color" was published at Bologna, two years after the death of its author, Francesca Maria Grimaldi, a Jesuit priest and astronomer. In this he recounts some interesting experiments, which did not, it is true, lead him to the wave theory of light, but served as the basis on which this theory was subsequently established. Similar experiments were made soon afterward by Robert Hooke, the ever-jealous rival of Newton, and by Christian Huygens, their distinguished Dutch contemporary. Huygens demonstrated that, if an impulse be given to any single particle in a uniformly elastic material medium, it must be propagated thence as wave-motion

equally in all directions; and that the propagation of a wave front in any given direction is the result of a multitude of interferences among the elementary waves started from the particles which are successively disturbed. Accepting this principle, the laws of reflection and refraction, whether of light or sound, follow immediately; and they were worked out with great skill by Huygens. Another consequence is, that if an obstacle be interposed in the path of a wave, its edges must serve as new centers around which secondary waves will be propagated, while the main wave continues to advance. This is familiar in the case of water-waves.

If, therefore, light be due to wave-motion, no perfect geometric shadow is possible, for the shadow must suffer encroachment from these secondary waves thus diffracted. Such phenomena were actually observed in the case of light by Grimaldi, Hooke, and Huygens, but no satisfactory explanation was then given. It is surprising that Huygens did not think of applying the theory which had been so satisfactory in its application to other optical phenomena. He had not attempted to measure the length of waves of light, and had no conception of their exceeding minuteness. If any diffraction phenomena were to be observed, the encroachment for which he naturally looked was far greater than what had been noticed as inexplicable and almost imperceptibly narrow fringes. The absence of the diffraction phenomena such as he may have expected did not cause him to abandon his wave theory, though he could not but perceive that it constituted a stumbling-block. To the mind of Newton this obstacle was insuperable; it determined his rejection of Huygens's theory.

If Newton was not the inventor of the emission theory of light, he was certainly its most ardent advocate. It came into prominence along with the wave theory, or indeed a little after this; and by means of it very satisfactory explanations could be given of most optical phenomena. Newton's reasoning, and the authority of his great name, caused its acceptance by all contemporary physicists, except Hooke, Huygens, and Euler, and by all his successors for a century. Whichever of the two theories is accepted, assumptions are involved which are open to attack and incapable of being substantiated on any antecedent grounds. Its value has to be measured alone by its consistency with observed facts. It was not until about the beginning of the present century that Dr. Thomas Young revived the long-discarded wave theory, explained the diffraction of light by its aid, and showed the incompetency of the emission theory. His views were at first generally rejected, but in time they attracted the attention of Arago and Fresnel. The latter especially entered into the investigation with enthusiasm, and completed the establishment of the wave theory upon foundations that have never since been successfully assailed. The elastic

medium required for the propagation of light-waves, whether through interplanetary space or terrestrial bodies, is the universal ether, of whose existence we have no evidence except that, by assuming it and applying mathematics, the results of computation are exactly corroborated by observation and experiment. The elastic medium required for sound-waves may be solid, liquid, or gaseous. In any case it must be material.

Assuming, then, an obstacle in the path of a wave of sound or light, a shadow should be produced; but since the edges are sources of secondary waves, according to Huygens's principle, these should encroach upon the shadow. The degree of encroachment can be expressed in a mathematical formula, and is thus shown to be proportional to the wave-length. The average length of a wave of green light is now known to be about $\frac{1}{50000}$ of an inch. The encroachment on the geometric shadow is hence so small that refined methods are needed to make it perceptible. In the case of audible sound, on the contrary, when propagated through air, the wave-length is ordinarily so great that the encroachment almost wholly masks the presence of any shadow whatever. For the pitch C, 132 vibrations per second, such as is often used by men in conversation, the wave-length is readily calculated, if we know the velocity of sound in air. Taking this as 1,120 feet per second, there will be 132 waves strung out over this distance in each second. The length of each is hence eight feet and six inches, or more than five million times as great as that of the average wave of light. For such waves it is hopeless to attempt producing any well-defined shadows.

One of the most familiar facts in physics is that the pitch of a note becomes higher, and hence its wave shorter, in proportion to the increase of vibration frequency. If well-defined sound-shadows are possible, we must resort to sounds of very short wave-length. If the sound is continuous instead of explosive, this shortness implies very high pitch. There are mechanical difficulties to contend with which make it hard to give much intensity to very acute sounds. The range of audition, moreover, is limited. For persons of good ear the range may be roughly stated as from 25 to 25,000 vibrations per second for sounds of small intensity; indeed, many fail to perceive any pitch exceeding 15,000. To exhibit sound-shadows, therefore, it becomes necessary either to employ a source that sends forth sounds of such high pitch as to be inaudible to most of those who are expected to perceive the shadow, or to resort to a momentary sound of great intensity and short wave-length.

Every one has noticed the decrease in intensity of the sound of a distant railway-train as it passes into a cutting. The observer is in a shadow which is incomplete but nevertheless noticeable.

The secondary waves, which are started at the upper edges of the cutting, reach the ear and give still a good idea of the character of the noise and position of the train. The range of the ear greatly exceeds that of the eye, not only in relation to the variety of wave-lengths by which it may be impressed, but yet more as to variations of intensity. Just as sunshine and shadow during the day indicate merely variations in illumination without the complete extinction of light, so noise and sound-shadow are merely relative terms, the latter not necessarily implying the complete extinction of sound; for in air diffraction usually plays so important a part as to forbid complete extinction, and to prevent all sharpness of definition at the edges of the shadow.

When the medium is water instead of air, some new phenomena are noticeable. In 1826 Daniel Colladon's classic experiments on the velocity of sound in water were performed on the Lake of Geneva. The source of sound was a large bell, from which vibrations were conducted through the water several miles away to an elastic membrane stretched across the expanded opening of a partially submerged hearing-trumpet. They were thus given to the air within the trumpet and conveyed to an ear applied at its smaller end above the water. A bell when struck sends forth a variety of tones, and it is often hard to determine which of these is most prominent. Usually that of deepest pitch is the slowest to die away in air, and often it penetrates to the greatest distance. Colladon made the remarkable observation that in water the lower tones are conducted off to but a short distance before their energy ceases to produce the sensation of sound; while the initial stroke is propagated much further, and is then perceived as a short, sharp, almost clicking sound, without definite musical character. Placing the hearing-trumpet behind a wall which projected out into the water, the decrease of intensity was much greater than under similar conditions in air, and the demarkation of the region of shadow was decidedly more noticeable.

Still more interesting than the experiments of Colladon were those made in the Bay of San Francisco in 1874 by Prof. John Le Conte and his son, Mr. Julian Le Conte. The source of sound was not such as would give a definite pitch, like a bell, but the quick, violent, single impulse due to the explosion of dynamite employed in the blasting of rocks which obstructed the channels. The intensity of the shock thus propagated was such as to be felt as a blow on the feet of a person seated in a boat three hundred feet or more from the detonating cartridge, and to kill hundreds of fish. Several vertical posts or piles, each about a foot in diameter, projected from the ground out of the water in the neighborhood. A stout glass bottle was suspended in the water about a foot in the rear of one of these piles (Fig. 1), within the geomet-

ric shadow determined by lines supposed to be drawn from the cartridge forty feet horizontally away. The bottle was perfectly protected from the shock of the explosion. It was then put in front of the pile. The first shock shivered it into hundreds of fragments. Other bottles, some filled with air and some with

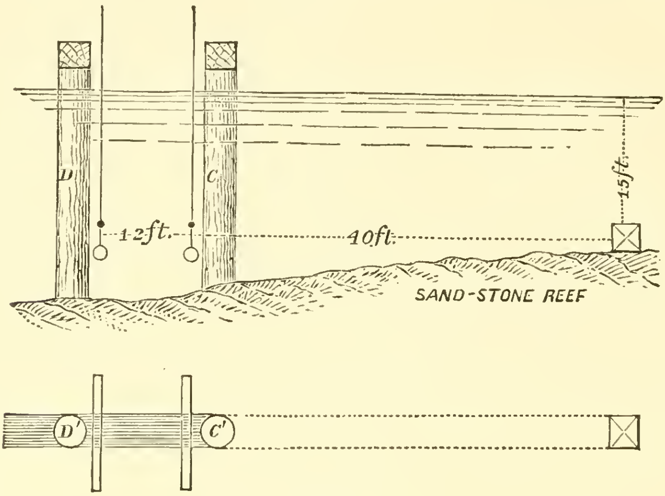

Fig. 1.

water, were similarly exposed in various directions around the pile, and with the same result—destruction, except when within the protecting shadow. The experiments were varied by immersing stout glass tubes (Fig. 1), incased in thick paper, horizontally across the direction of the sound-rays in water, between two piles which were aligned with the dynamite cartridge. These piles were twelve feet apart, the nearer one being forty feet from the cartridge. Its shadow, therefore, just covered the second pile, and included the intermediate water, with the middle part of each tube. After an explosion these protected parts were found to be unbroken, while the ends

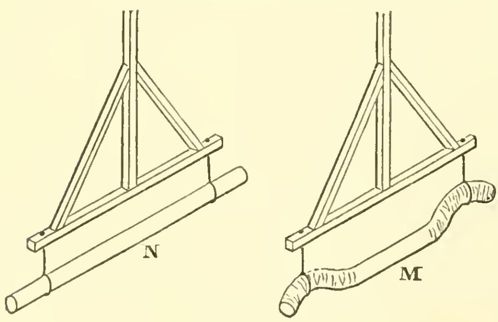

Fig. 2.

which projected on the two sides beyond the shadow were completely shattered (Fig. 2). The boundary between the regions of shadow and noise was sharply defined on the tubes, even at a distance of twelve feet behind the protecting pile.

To account for the shortness of. the sound-waves which were

capable of producing such sharp shadows, Dr. Le Conte advances what seems to be the only tenable theory, and one which equally explains the observations of Colladon on the clicking sound of a distant bell as heard in water. In the absence of any recognizable pitch—for pitch implies a series of impulses recurring in regular order—there is no means of determining wave-length in these cases. But whatever this may be, the wave-length is equal to the product of the time consumed in generating the wave and the velocity of propagation. Thus, assume the initial pitch of a bell to be 220 vibrations per second. We may compute the wave-length either by considering that 220 waves are strung out over a distance of 1,120 feet, making each a trifle more than five feet long, or we may say that the time consumed in generating each wave is $\frac{1}{220}$ of a second, and that this impulse is propagated at the rate of 1,120 feet per second, which would be a little over five feet in $\frac{1}{220}$ of a second. The blow of the hammer on Colladon's bell was almost instantaneous, and the intensity of the first shock thus given to the water was far greater than that of any subsequent shock due to the succession of vibrations set up in the elastic bell-metal. The distance through which this intense sound would be propagated might be expected greatly to exceed that traversed by the subsequent weaker vibrations. The generating blow was so brief that the wave-length could only be short; and hence comparatively well-defined sound-shadows were produced at a distance. In the case of the dynamite explosions under water this reasoning holds with yet greater force. If the duration of the generating impulse be only a millionth of a second, and the velocity of propagation in water be 4,700 feet per second, the resulting wave-length would be only about $\frac{1}{17}$ of an inch. The quickness of action manifested in the explosion of dynamite exceeds that of any other known agent that has ever been similarly employed. The duration of the generating impulse may be considered indefinitely small, certainly immeasurably small. The sharpness of the sound-shadows it produces in water indicates a wave-length that can not exceed a small fraction of an inch.

The production of sharp sound-shadows in air is of more recent date than the experiments in water. In 1880 a dynamite-factory near San Francisco was destroyed by the explosion of its contents. On a large building three miles away many panes of window glass on the side toward the explosion were broken, and two shocks were felt, one conducted by the air and the other by the ground. In the acoustic shadow cast by this building, nearly nine hundred feet away on the side remote from the explosion, no aërial shock was experienced, though that from the ground was distinctly felt. The shortness of the air-wave due to exploding dynamite sufficiently accounts for the sharpness of the shadow.

But there is now no longer any necessity to resort to such dangerous sources of sound as dynamite. Whistles may be made which yield tones exceeding twenty thousand vibrations per second. The wave-length corresponding to such a pitch is less than an inch. The advantage presented is that the sound is continuous, and it may be made as constant as we please by supplying the whistle from a cylinder full of compressed air, regulating the pressure by means of an appropriate gauge. The disadvantage is that the intensity is but slight, and the pitch is too high to be perceived as sound by most persons unless the ear is closely applied. An artificial indicator must hence be used, whose motion under the disturbances due to sound can be seen at a distance.

In 1857 Prof. John Le Conte discovered that an ordinary naked gas-flame, from a fish-tail or bat-wing burner, becomes an indicator of sound by vibrating in unison with an external source, provided the pressure be such that the flame is just ready to flare. This can be easily shown by blowing a shrill whistle or bowing a tuning-fork of high pitch in the immediate neighborhood of the flame, which at once becomes forked (Fig. 3) into several long, vibrating tongues. The effect soon ceases if the pressure be gradually diminished. This result is due to the disturbance produced by sound-waves on the outflowing jet of gas at the nozzle. The high temperature of flame is therefore not necessary for the production of such co-vibration, but serves to make it more easily manifest.

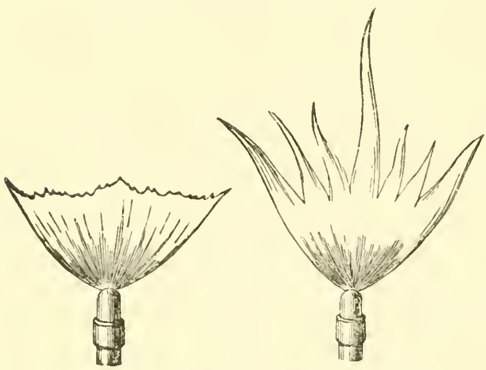

FIG. 3.—SENSITIVE BATWING FLAMES.

Nine years elapsed after Dr. Le Conte's discovery before the subject was taken up again and independently by Mr. W. F. Barrett, in London, who used small cylindrical jets, which were found to flare under similar conditions, and could be rendered far more sensitive. A "pin-hole lava-tip" may be fitted into the end of a metal tube and connected by means of India-rubber tubing to a cylinder of compressed illuminating gas. In connection with this, also, there should be a water manometer gauge for regulating the pressure of the outflowing gas. If the pin-hole is very smoothly cylindrical, the flame mounts up to the height of nearly eighteen inches (Fig. 4, *a*), with an apparent thickness scarcely more than that of the little finger, and burning quietly. When the pressure approaches ten inches, as indi-

cated by the water-gauge, the flame flares, becoming much shorter and broader, like a little Indian club (Fig. 4, *y*), and producing a low roaring sound, due to the escape of unburned gas. Let the pressure now be diminished until this flaring barely ceases. The flame is now in its most sensitive condition. Sounds of low or even medium pitch have no effect upon it; but on blowing a shrill whistle, or rattling a bunch of keys anywhere within thirty or forty feet, it flares. Perhaps the most beautiful illustration of its sensitiveness is given by placing an open watch near the nozzle but not touching it; every tick causes a momentary sinking and spreading of the flame, so that the effect may be seen across an audience-room. If the audience applauds with clapping of hands, the flame shrinks in acknowledgment.

A very sensitive flame, but not so convenient as that of Prof. Barrett, and not visible at so great a distance, may be obtained with no pressure greater than that of the street mains, by causing the gas to issue from a small tube, over the orifice of which, at a height of an inch or two, is placed a piece of wire gauze (Fig. 5). The mixture of coal-gas and air is ignited above the gauze, and a glass tube may be used to protect the flame from currents of air, though this is not usually necessary. Very little adjustment is needed to find the distance between nozzle and gauze at which the flame is most sensitive. This arrangement was devised independently by Prof. Govi, of Turin, and Mr. Barry, of Ireland. The flame is deficient in brightness, and is only a few inches high at its best, but has the advantage of not requiring any appliances that may not be easily supplied in any town. If Barrett's flame is available, however, it is decidedly preferable to anything else.

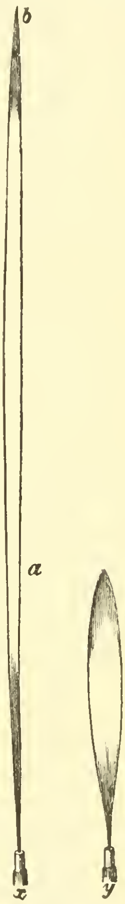

Fig. 4.

With such a flame as Barrett's it becomes possible to explore the air and detect regions of relative noise and silence' just as a delicate thermometer enables us to determine variations of temperature in different layers of air or water. If the pitch be too high for the ear to estimate or even detect it, the sensitive flame is more delicate than the ear. Armed with a whistle yielding a pitch of twelve or fifteen thousand vibrations per second, and with a good flame, many beautiful analogies between sound and light may be exhibited with entire satisfaction to an audience of deaf-mutes, if the lecturer's fingers are fairly nimble, since there is no necessity for the sounds to be heard. Most of the experiments about to be described were devised by Lord Rayleigh, the suc-

cessor of Prof. Tyndall in the chair of Natural Philosophy at the Royal Institution in London.

Let the whistle be supplied with a continuous blast of air, or any compressed gas, at steady pressure. Four or five feet away from it is placed the nozzle of the burner from which the flame issues. Its sensitiveness may be regulated at will by means of the stop-cock and the water manometer gauge. Turning on the blast through the whistle, the flame flares. Let the open hand be held up between the two; the flaring ceases. The nozzle of the burner is in the acoustic shadow cast by the hand. If this result is not successfully attained at the first trial, the sensitiveness of the flame may be slightly modified to suit the conditions. The case is entirely analogous to that of the glass bottles in the experiments in San Francisco Bay.

By using a small mirror to reflect the sound-waves, their lengths may easily be measured in mid-air. Let the mirror be put a few inches behind the flame and moved slowly toward this or away from it. At certain distances the flame is observed to flare violently, and at certain other points it becomes quiet, though the sound has not been varied. Reflected waves are meeting advancing waves. Where they meet in like phases, their effect on the flame is intensified. But if the position of the mirror is so adjusted that the flame is at a point where the opposing waves meet in unlike phase, these neutralize each other and the flame ceases to be agitated. The case is like that of producing loops and nodes on a string attached at one end to a vibrating body and fixed at the other end. A series of sinusoidal curves travel over its length, and are reflected from the fixed end, producing the so-called stationary waves (Fig. 6). A returning sinusoid is superimposed on an advancing sinusoid, producing two loops, with an intermediate nodal point of rest and a node at the end. The whole sinusoid represents a wave-length, and the distance from node to node a half wave-length. The distance through which the mirror is moved from one point of flame quiescence to the next is a half wave-length for the pitch yielded by the whistle. In some experiments thus conducted by the writer, this distance was found to be a trifle over half an inch. The whole wave-length was 1·05 inch. Assuming the velocity of

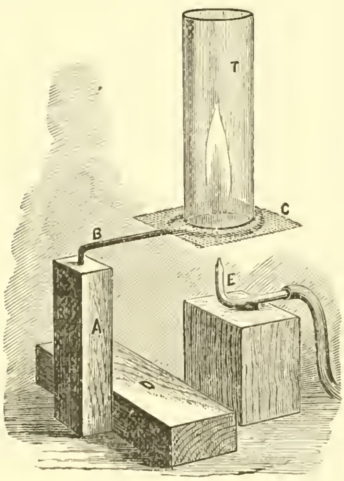

Fig. 5.

sound to be 1,120 feet, reducing this to inches, and dividing by 1·05 inch, the pitch of the whistle was thus found to be in the neighborhood of thirteen thousand complete vibrations per second. In no other way could this pitch be determined, for the most accomplished musician loses his power of discriminating pitch when either the upper or the lower limit of audition is approached. The pitch of the highest tone employed in music does not exceed five thousand vibrations per second.

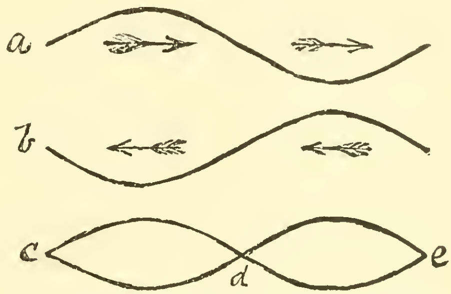

FIG. 6.—*a*, advancing sinusoid; *b*, returning sinusoid; *c*, advancing and returning sinusoids, forming two loops and a node; *c e* is a whole wave-length; *c d*, a half wave-length.

In performing this experiment Lord Rayleigh discovered an interesting peculiarity of the human ear in contrast with the sensitive flame. By using a tube, whose opening was placed alternately in the aërial loops and nodes, and conveying the sound thus to the ear at the same time that the flame was alternately agitated and quiescent, he found that the ear was most affected where the flame was least affected, and *vice versa.*

The flame, moreover, is unequally sensitive in two directions at right angles with each other. In drilling the small cylindrical hole of the burner no amount of care is sufficient to prevent minute irregularities. The current of issuing gas is not absolutely cylindrical. It is disturbed slightly by interior currents from side to side, and these affect the sensitiveness of the jet to external disturbances. To test this, let the nozzle be rotated on its own axis while the whistle is sounding, until the maximum effect is noticed; and let the sensitiveness of the flame be slightly reduced without causing it to cease to flare. On rotating the nozzle now through a right angle the flame is found to become quiet. Let a mirror be put on one side of the flame, a short distance off, so as to face the sensitive side. Adjusting it until it is equally inclined to the directions of flame and whistle, the flaring is started anew. This ceases when the mirror is rotated toward either side through a very small angle. Indeed, no more beautiful and exact illustration could be devised for showing the law of reflection of sound-waves. The sound-ray, taking a longer and broken path, disturbs the flame on its sensitive side, while the direct rays are at the same time beating in vain against what by analogy we may call its deaf side.

Probably the most interesting acoustic phenomena to be investigated by the aid of the sensitive flame are those of diffrac-

tion, or the measurable encroachment upon sound-shadows. In the accompanying diagram (Fig. 7) suppose the arrows to represent the direction of a group of parallel rays of either sound or light, the wave fronts being indicated by lines across the direction of the arrows. Waves in one phase are indicated by the continuous lines, and those in opposite phase by the dotted lines. At each edge of the obstacle are the centers of the secondary waves, whose fronts are represented by parts of circles. Behind the obstacle and on each side are points of interference represented by crosses

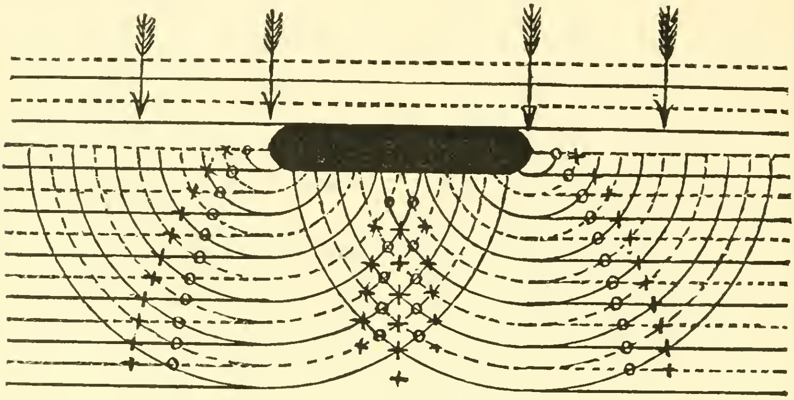

Fig. 7.—Exterior and Interior Diffraction.

and zeros. Behind it the secondary waves from opposite edges meet each other. At the sides, secondary waves interfere with the advancing main wave. Where like phases meet, the crosses represent points of increased disturbance. Where opposite phases meet, the zeros represent points of quiescence. If the waves are those of light, the crosses are points of increased brightness; the zeros, of comparative darkness. If the waves are those of sound, the crosses are points of noise; the zeros, of silence. Behind the obstacle there is a middle line of crosses; on each side of this a line of zeros; and outside of these are lines of crosses again. These lines are parts of hyperbolas, whose foci are the centers from which the secondary waves are started. This is readily seen by reference to the next illustration (Fig. 8). A necessary consequence is, that if light radiating from a point or a small aperture be interrupted by interposing a small disk in its path, there should be a line along the middle of the shadow behind it, at certain points of which brightness appears if a translucent screen is placed across the shadow. This fact was noticed by a Frenchman, Delisle, before the birth of either Newton or Huygens, but was of course not understood and was soon forgotten. Dr. Young seems not to have thought of it, or certainly never put this consequence

of theory to any test. The first physicist to recognize the value of Young's optical papers was Arago, who at once adopted the wave theory and started his friend Fresnel on a series of optical researches that are now classic. In 1819 Fresnel gained a prize from the French Academy for his work on diffraction of light. Before the report was made to the Academy it was examined by the mathematician Poisson, who criticised it by showing that, if the wave theory were accepted, the shadow of a small disk should have a bright spot in the middle, due to diffraction, the illumination of which should be the same as if no disk had been interposed. Arago at once tried the experiment; and what Poisson had urged to prove the impossibility of Fresnel's views was found to be a startling proof of their correctness. The experiment is easily tested, requiring no more expensive apparatus than a mirror outside of an opening in a window, a small bullet suspended by a thin wire, and a piece of roughened glass to receive the shadow. A pin-hole through a sheet of tin foil covering the window opening yields the required light from the mirror. The acoustic analogue of this celebrated experiment was first accomplished a few years ago by Lord Rayleigh; it has been lately often repeated by the writer and perhaps others. A disk of cardboard about a foot in diameter is put between a whistle and sensitive flame, with careful adjustment of distance and sensitiveness. In certain positions the flame is protected within the shadow of the disk; but, by moving the latter to and fro, one position is found where it causes the flame to be violently agitated by the meeting of waves diffracted at the edge of the circle. The diffractive effect is the same as if the impervious disk were a lens converging the sound-waves to a focus.

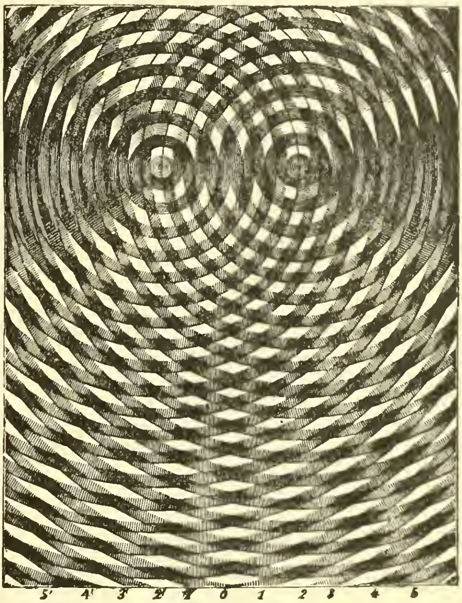

Fig. 8.—Hyperbolas produced by Interference of Waves.

The effect just described may be much intensified by constructing an acoustic diffraction grating and using it in place of the simple disk. The explanation of the principle on which such a

grating is made is beyond the scope of the present paper.* Assuming its use, the sensitive flame enables us to detect a focal area of noise, at which the flame is violently agitated, and around this are alternate rings of silence and fainter noise diminishing in strength with increase of distance from the central focus.

By admitting light through two small openings close together, the waves coming from a distant bright point and hence reaching the two openings in the same phase, hyperbolic lines of interference like those shown in Fig. 8 were traced in space by Fresnel. The writer has recently done the same with sound-waves, using the sensitive flame as an explorer. Bands of alternate noise and silence have in like manner been traced by him in air, produced by interference between the waves proceeding directly from the whistle and those reflected from a smooth surface placed horizontally on the table.

The wave theory of sound has long been impregnable; but these beautiful analogies between light and sound, though provided for by theory, have been experimentally demonstrated only recently. Such new and unexpected confirmations, new points of contact, are always welcome, even though they be not needed for the establishment of a theory. They are the results of prevision based on the assumption that an elastic material medium is needed for the propagation of sound, and are wholly inexplicable on any theory of emanation analogous to Newton's emission theory of light.

* For this explanation the reader is referred to an article on "Diffraction of Sound," in the "Journal of the Franklin Institute," for June, 1889.

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